P-24: Plasma Physics

Development of Methods for Obtaining On- and Off-Hugoniot Equation-of-State Data Using Laser-Driven Shocks

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This project investigates advanced equation-of-state (EOS) experimental techniques relevant to measurements such as those suggested for the proposed Trident-Upgrade laser facility at Los Alamos. Experiments, which recently began at the Nova laser facility of Lawrence Livermore National Laboratory (LLNL), are focused toward simultaneous measurements of the direct-laser-drive principal Hugoniot (PH) and zero-pressure-release isentropes of beryllium. Beryllium was chosen as the EOS sample because it is an important inertial confinement fusion (ICF) material with particular relevance to National Ignition Facility (NIF) capsule designs. Furthermore, its low x-ray opacity and high shock and particle speed—in comparison with denser metals—make beryllium an ideal material with which to develop these advanced techniques. Direct drive with side-on x-ray radiography is believed to be the optimum approach toward obtaining a high-accuracy, laser-based EOS. To this end, a novel, one-dimensional, state-of-the-art x-ray microscope, designed by P-24 researchers, has been conceived and is currently under fabrication. Upon completion of this x-ray device, experimental work will be transferred to the Omega laser facility at the University of Rochester. The completion of an active shock-breakout diagnostic in the future will extend this project to include the novel addition of "sound speed" to the PH and isentrope measurements.

Design of Weapons-Physics Experiments Driven by X-Rays from the PBFA-Z Pulsed-Power Facility at Sandia and the Nova Laser at Livermore

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We are evaluating the PBFA-Z pulsed-power facility at Sandia National Laboratories in Albuquerque (SNL) as an x-ray source for weapons-physics experiments. PBFA-II, originally constructed as a set of 36 light-ion-beam accelerators for ICF experiments, has been reconfigured as PBFA-Z to drive z-pinch implosions using wire-array loads. The implosion efficiently converts the electrical energy in the pulsed-power system into x-rays when the imploding wire plasma stagnates on the cylindrical axis. The initial operation of this reconfigured facility has been very encouraging. X-ray yields of ~2 MJ and peak powers of ~200 TW in 25-cm^3 hohlraums have been produced in early experiments, corresponding to peak black-body temperatures of 100 eV. We are planning to reduce the hohlraum volume to ~5 cm^3 in an effort to raise the peak temperature to 120 eV or more. These hohlraums will be used for studies of foam-filled tubes with diameters in the range of 2.4–5 mm. Similar x-ray drive conditions can also be produced in laser-driven hohlraums on the Nova laser at LLNL but are limited to smaller-diameter tubes. The smaller size of the laser-driven targets is partially offset by the superior imaging diagnostics at the Nova facility. In both the pulsed-power and laser facilities, development of improved x-radiographic capabilities will be important for our above-ground studies.

Fusion Neutrons from the Gas/Pusher Interface in Deuterated-Shell ICF Implosions

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In this project we have performed the first measurements and numerical simulations of fusion neutrons from the gas/pusher interface of indirectly driven ICF implosions using hydrogen-filled capsules made with a deuterated inner layer. Contrary to the case of conventional capsules with D-T (deuterium-tritium) or D-D (deuterium-deuterium) gas fills, neutron yields in these capsules are due mostly to undesirable mix at the pusher/gas interface. We varied the nonlinear saturation of the growth of hydrodynamic perturbations in implosions with high linear growth factors (~325) by adjusting the initial surface roughness of the capsule. The neutron yields are in quantitative agreement with the direct simulations of perturbation growth, and they also agree with a linear-mode superposition and saturation model, including enhanced thermal loss in the mixed region. Neutron spectra from these capsules are broader than expected for the calculated ion temperatures, suggesting the presence of nonthermal broadening from mass motion during the fusion burn.

Instability-Coupling Experiments on the Nova Laser

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Our research team is studying the coupling of Richtmyer-Meshkov (RM) and ablative Rayleigh-Taylor (ART) instabilities with indirectly driven, planar foil experiments on the Nova laser at Livermore. The foil is attached to a 1.6-mm-diameter, 2.75-mm-long gold hohlraum driven by a shaped laser pulse that is 2.2 ns long with a contrast ratio of 1:5. A shock is generated in 35-μm- or 86-μm-thick aluminum foils with a sinusoidal perturbation (with a wavelength of 50 μm and an amplitude of 4 μm) on its rear surface. In some experiments the perturbation is applied to a 10-μm beryllium layer on the aluminum. An RM instability develops when the shock encounters the perturbed surface. The flow field of the RM instability can "feed out" to the ablation surface of the foil and provide the seed for ART perturbation growth. This is an important problem for ICF, in which the nonuniformity in the D-T ice surface inside the capsule can feed ART growth in the capsule exterior. We use face-on and side-on x-radiography to observe areal density perturbations in the foil. For the 86-μm foil, the perturbation arrives at the ablation surface while the hohlraum drive is dropping, and the data are consistent with RM instability alone. For the 35-μm foil, the perturbation feeds out while the hohlraum drive is close to its peak, and the data appear to show strong ART perturbation growth. The data are in generally good agreement with LASNEX simulations (simulations performed with the Los Alamos version of the ICF design code first developed at Livermore) except that the simulations do not reproduce the strong development of a second harmonic in the thin aluminum samples.

High-Intensity Illumination of an Exploding Foil

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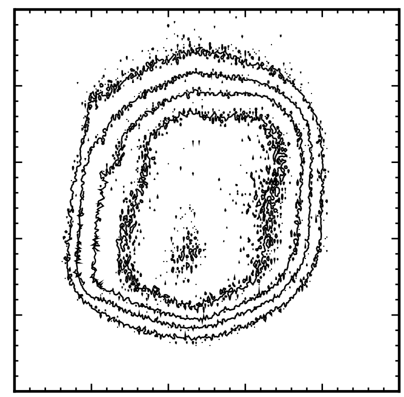
Successful ICF involves the compression of a D-T fuel to sufficiently high density, ignition in a hohlraum hot spot within the fuel, and a propagating fusion burn within the fuel. Conventional ICF relies on carefully timed, converging shocks driven by the compression beams. A promising alternate concept, the "fast-ignitor," relies on a high-intensity laser to light the hot spot on the preassembled fuel. In order to achieve that, the beam must propagate through the underdense plasma surrounding the capsule, where laser-plasma instability could break up the beam.

During the first year of research, we employed the short-pulse capability of the Trident laser at Los Alamos to measure the penetration of a high-intensity beam through a 1-mm-scale-length, underdense, C-H plasma. The highest laser irradiance was 7×10^{18} W/cm^2. The plasma density is controlled via the delay between the low-intensity plasma-formation beam and the high-intensity probe beam. Our experiment used plasmas of several percent of the critical electron density (above this critical density the laser cannot propagate). The probe beam was focused with an f/2.5 parabola. We found that the beam f number was increased after the beam had passed through the plasma; i.e., it was more collimated on account of its interaction with the plasma. In order to measure this effect, we allowed the transmitted beam to strike a diffuser plate behind the target. The scattered light from the plate was imaged by a camera to produce the data shown in Fig. III-1. We also measured the reflected and transmitted light for different delays (different plasma densities). Even at the low plasma densities used, the transmission was less than we had expected. Theoretical studies that attempt to model the behavior of the beam in the plasma are under way. Work from our first year of research will be published in *Physics of Plasmas.* More experiments, in which the plasma density and laser wavelength will be varied, are planned for 1997.

(a)



(b)

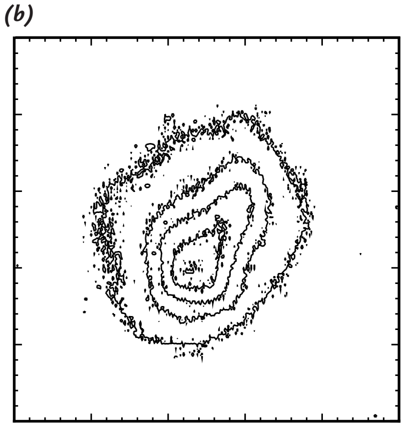


Fig. III-1. The f number of the probe beam is approximately doubled on passage through a 3% critical-density plasma. The case with no plasma is shown in (a); the case with a plasma is shown in (b). Each frame is an array of 250 × 250 pixels.

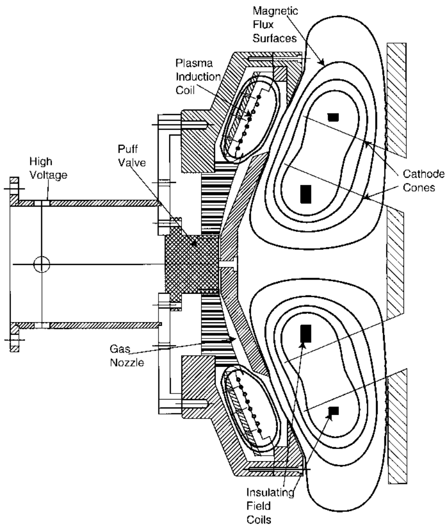


Fig. III-2. Design of the intense-ion-beam source.

Microsecond-Duration, Repetitive, Intense-Ion-Beam Accelerator

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A number of intense-ion-beam applications are emerging that require repetitive, high-average-power beams. These applications include ablative deposition of thin films, rapid melt and resolidification for surface-property enhancement, advanced diagnostic neutral beams for the next generation of tokamaks, and intense pulsed-neutron sources. We are developing an intense-ion-beam accelerator called CHAMP (continuous high-average-power microsecond pulser) with a beam energy of 250 keV, a beam current of 15 kA, a pulse length of 1 ms, and a pulse frequency of 1–30 Hz. The accelerator will use a magnetically insulated extraction diode in a ballistically focused geometry (see Fig. III-2). The 450-cm^2 active plasma anode (MAP diode) can utilize any gaseous species. Gas is supplied from a puff valve located on the system axis and is ducted through a radial flow channel. The anode plasma is formed by currents induced in the gas by a fast-rising, two-turn, flat, spiral-wound coil with four parallel sets of windings. The insulating transverse magnetic field will be generated by two magnetic-field coils on the grounded cathode focusing cones. We will use a set of parallel, lumped-element, Blumlein circuits and a step-up pulse transformer to supply the diode acceleration voltage. Our current work is centered on testing and optimizing the plasma-generation system.

Laser-Plasma Instability Research in Fusion-Ignition-Relevant Plasmas

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Laser-plasma instability could pose a threat to success in ICF either by scattering light outside of the target or spoiling the symmetric illumination of the fusion capsule. The speckled nature of laser beams used in ICF is an important factor in laser-plasma instability processes. Models that account for the laser speckles successfully predict the observed onsets of backscattering due to stimulated Brillouin scattering (SBS) and stimulated Raman scattering (SRS). Linear convective theory predicts very large levels of SRS backscattering from the long-scale plasmas expected in ignition hohlraums. Our observations of SRS saturation are inconsistent with linear theory scaling, but are qualitatively understood in terms of other processes. In particular, we have shown direct evidence for the dependence on acoustic damping of the SRS reflectivity of a 351-nm, random-phase-plate laser beam from a long-scale hohlraum plasma. Because SRS itself is unrelated to acoustic waves, this is evidence of other parametric processes determining the nonlinear saturation of Raman backscatter. We have great expectations from optical imaging diagnostics recently deployed at Nova. They could help elucidate important outstanding questions relating to SBS and SRS nonlinear saturation, and they could also prove to be valuable electron-density diagnostics.

Effort in Support of the Core Science and Technology Plan for Indirect-Drive ICF Ignition

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In conjunction with other researchers in MST and T Divisions, we have carried out a number of theoretical and experimental studies of nonlinear optical phenomena important to the design of the National Ignition Facility (NIF) laser. These studies include measurements of nonlinear refractive index coefficients (n_2), Raman scattering in atmospheric oxygen, and theoretical studies primarily of harmonic conversion. Our motivations for measuring n_2 were the relatively large scatter in the data that had been obtained for fused silica by different techniques at 355 nm and the importance of this effect in setting the size of optics at NIF in order to avoid damage due to self-focusing. Our results were consistent with the lower range of previously reported measurements and indicated that the chosen size for the NIF final optics assembly would not have to be increased; a larger optics assembly would have cost significantly more. We made our measurements by a modified Z-scan technique in which the intensity distribution of an initially flat top beam that is relay-imaged onto a charge-coupled device (CCD) camera is recorded when a sample is scanned through the focus. These measurements were also confirmed by MST-Division researchers using the recently developed ultrashort-pulse characterization technique of frequency-resolved optical gating, with which they determine phase shifts induced by propagation through a sample. The Raman-scattering studies were prompted by some earlier calculations, which indicated that the method that had been suggested to avoid rotational Raman scattering by nitrogen in long air paths at NIF would not be adequate. This suggested method—to place part of the propagation path in a breathable oxygen/argon atmosphere—would be inadequate because the Raman gain in the atmospheric concentration of oxygen is approximately 77% of the nitrogen gain. Experiments to measure the relative gains validated this calculation to within a few percent. The NIF design has since been altered to incorporate inert-gas beam tubes. Work in T Division on efficient, multiple-crystal, harmonic-conversion geometries for NIF has been extended to look at the effect of such geometries as a means of possibly mitigating phase perturbations that result from the baseline design, which are a major contributor to damage in downstream optics. We have observed some improvements with such designs, but we are still seeking an ideal case that maintains high conversion efficiencies. Ongoing work also includes the examination of multiphoton absorption effects in potassium dihydrogen phosphate (KDP) harmonic-conversion crystals and the pursuit of designs for spatial-filter pinholes that do not close because of rapid plasma production.

Plasma-Based Removal of Transuranic Contaminants from Surfaces

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The primary goal of this project is to develop and demonstrate the utility of plasma-based processes for the removal of transuranic (TRU) contamination from targets of interest to the DOE complex. The first stage of the process has been to design, fabricate, and perform initial tests of a small prototype plasma-decontamination system, using both uranium and nonradioactive surrogate contaminant materials. We have designed, fabricated, and integrated a small system (~0.5 m^3) with a two-stage cryogenic trapping and recovery system. Examination of the etching characteristics of various gases (including CF_4, NF_3, and SF_6) led to the selection of NF_3 as the plasma precursor gas because of its reduced potential for particulate formation and for nonvolatile material deposition. We have conducted experiments to examine the removal of various contaminant materials in a number of different target geometries. These geometries have included the removal of uranium contamination from the shielding material used in explosives tests as well as from the inside of relatively small diameter pipes (with an inside diameter of 1.25 cm and a length of 20 cm). We have also conducted a very large scale test (~3-m^2 target area) in another available facility. This test examined the removal of a very hard, chemically resistant, amorphous carbon material from the surface of an extremely complex aluminum target. We used an oxygen plasma in this case as an analogue for the fluorine-based plasma that would be used to volitalize and remove plutonium or uranium from contaminated surfaces. Experiments with NF_3 and tungsten (as the TRU surrogate) have demonstrated material-removal rates in a mild, reactive-ion-etching (RIE) mode. These rates are nearly an order of magnitude faster than the material-removal rates we observed in the plasma-immersion mode. Tests using uranium have demonstrated >99% removal of the original contaminant, based on surface alpha-count techniques. Experimental work is now moving in the direction of direct demonstrations using plutonium-contaminated surfaces.

Plasma-Source Ion Implantation and Plasma-Immersion Ion Processing

C.Munson [(505) 667-7509], J.T.Scheuer, B.P.Wood (P-24)

Plasma-source ion implantation (PSII) and plasma-immersion ion processing (PIIP) can be used to provide economical surface modification in order to satisfy industrial and DOE needs. These technologies promise low-cost methods with widespread application for the manufacture and utilization of high-strength, low-friction, corrosion-resistant, or biocompatible materials. R&D is focused on recipe development and materials characterization, pulsed-power equipment development, advanced inductive plasma sources and plasma diagnostics, and manufacturing process controls. Important applications include the following:

Advanced manufacturing. Work in this project includes demonstration implants on industrial components and high-temperature implantation experiments. In addition, we have developed a process to deposit adherent diamond-like carbon films on steels, and we have designed and fabricated a solid-state, insulated-gate, bipolar transistor modulator.

Automotive and other industries. This program, supported by DOE and NIST, involves a vertically integrated consortium of approximately more than a dozen industrial partners directed toward the commercialization of PSII techniques for these industries.

Gun barrels on tanks. In this project we are developing highly adherent coatings for wear- and corrosion-resistant gun barrels. This project supports Army work and involves ion implantation and deposition with plasmas inside 120-mm gun barrels on tanks.

Liquid-metal containment. This area includes containment associated with metal-casting of actinides (for Advanced Design and Production Technology) and of aluminum and magnesium (for industry).

Machine tools. The goal of this project is to commercialize PSII in order to extend the life of machine tools. Los Alamos, the site of the world's largest PSII facility, has teamed with Empire Hard Chrome (EHC) of Chicago, Illinois, to construct the world's first commercial PSII facility. To make this venture a success, Los Alamos will provide hands-on training of EHC equipment operators as well as the plasma and materials expertise that EHC requires to develop recipes, optimize conditions, and qualify applications.

Pistons and automotive tooling. We have successfully completed our major technical goals in this CRADA between Los Alamos and General Motors.

Pits. We are supporting the Nuclear Weapons Technology weapons-surety program by using PSII to develop fire-resistant erbia coatings for pits. In addition, we are developing molten-plutonium-resistant coatings for near-net-shape casting molds, a project that supports the pit-rebuild program.

Penning Fusion Experiment

M.M.Schauer [(505) 665-6014], T.B.Mitchell (P-24), D.C.Barnes (XCM)

The Los Alamos Penning Fusion Experiment seeks to confine high-density, nonneutral plasmas in a Penning trap. These traps combine static electric and magnetic fields to confine charged particles for up to several hours. However, because the traps can hold only a single charge, we are restricted to nonneutral plasmas, and the resulting space charge limits the ultimate density we can attain. The limiting value is known as the Brillouin density. In these experiments we have demonstrated the feasibility of forming a high-density core plasma in a volume-averaged, sub-Brillouin-density electron plasma through spherical focusing of the plasma. This is achieved by tuning the electric and magnetic fields of the trap so that the effective well seen by the electrons is spherical. Hence, the electrons are reflected by the well toward the center of the trap and form a high-density focus. We have seen conclusive evidence of the existence of such a focus in the form of scattering resonances in the trap parameter space. Electron-density distributions inferred from collected data indicate a peak density 35 times the limiting Brillouin value. In addition, we have documented an interesting hysteresis in the onset of the focus as a function of pumping current. Our future plans include an experiment that will confine ions in the virtual cathode provided by the confined-electron space charge.

Particle Removal in a High-Pressure Plasma

G.S.Selwyn [(505) 665-7359] (P-24), collaborators from Beta-Squared, Inc.

Plasma processes are used in 35% of the process steps needed to fabricate a semiconductor device. Particle contamination is a serious problem encountered during fabrication of devices and is a problem exacerbated by the formation of particulate contamination during plasma processing. Also, cleaning steps required to prepare semiconductor surfaces for processing consume several million gallons of water each day for a large foundry, and the use of solvents also required for surface cleaning produces chemical waste and ground-water pollution. Plasma processes may be used to clean wafer surfaces and materials of interest to DOE. The development of this technology offers an approach that is pollution-free because it uses harmless, inert gases; that may be done *in situ* prior to processing steps inside a plasma tool; that rapidly cleans the entire wafer while it is under vacuum; and that avoids redeposition of removed particulate matter back onto the wafer.

The first phase of this technology development was the demonstration of particle removal from wafer surfaces by plasma processes. In this collaboration, LANL applied its knowledge and skills in the development of technology for particle detection and removal from surfaces; Beta Squared, Inc., applied its capabilities in the design of a plasma tool suitable for use with this technology. This program proved highly successful: the Laboratory and Beta Squared, Inc., collaborated to build a prototype tool and successfully demonstrated that particulate contamination could be removed from wafers using plasma processes. The technology is suitable for immediate use on processing tools; a patent is currently in preparation. The same technology can now be applied for the development of a nonpolluting and nonhazardous method for removal of radioactive dust from surfaces. This can offer substantial benefits in cost-effectiveness and safety for decontamination and cleanup of contaminated areas.

Pollution-Free Plasma Cleaning of Materials

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A new plasma process is being developed at LANL and at the University of California at Los Angeles (UCLA) for the pollution-free cleaning of materials. In addition to the R&D 100 Award–winning PLASMAX cleaning process, which uses a novel plasma/mechanical process for removal of particulate contamination, we have recently invented an Atmospheric-Pressure Plasma Jet (APPJ) that is capable of removing organic, metallic, and oxide contaminants from materials at rates between 1 and 15 μm/h. These rates are up to ten times faster than can be achieved with conventional, low-pressure plasmas. The APPJ does not require a process chamber; thus, it can decontaminate materials of any size and shape, and it can be used out in the field if necessary. The jet is not like a plasma torch, which ionizes gas through excessive heating. Instead, the APPJ produces a stream of electronically excited metastable and radical species at about 450 K. This makes it safe for use on a wide variety of materials.

We are pursuing several applications for the plasma jet, including the decontamination of nuclear wastes and the cleaning of silicon wafers during integrated-circuit manufacturing. In the former case, the APPJ will etch away plutonium deposits on objects so that they may be reclassified from transuranic to low-level radioactive waste. We have won a $1.2-million DOE Environmental Management Science Program award to develop the science and technology of plasma-jet decontamination of nuclear wastes. The APPJ may also be used to clean semiconductor substrates. Currently, silicon wafers are cleaned with large quantities of deionized water, acid, and organic solvents. The industry wants to replace these wet-chemical methods because they are expensive, are hazardous to workers' health, and can pollute the environment. The APPJ is a promising alternative for wafer cleaning that uses no toxic chemicals and will not pollute the environment. In FY98 we will investigate the physics and chemistry of APPJ etching of tungsten and tantalum films (surrogate metals for plutonium) and of photoresists from silicon wafers. The plasma-source physics and gas chemistry will be investigated at LANL, and the surface chemistry of etching materials will be studied at UCLA. We are hopeful that this research will lead to a new, pollution-free technology for the cleaning and decontamination of materials.

Ion Sources for Etching and Deposition

M.Tuszewski [(505) 667-3566], J.T.Scheuer, J.A.Tobin (P-24)

Inductively coupled plasmas (ICPs) are used increasingly by the semiconductor and other industries as an important class of relatively high density (10^{11}–10^{12} ions/cm^3), low-pressure (1–10 mtorr) plasma sources for etching and deposition processes. Such high-density plasma sources can meet the industrial requirements of submicron feature size, low contamination, and high throughput. We have developed several novel ICP plasma sources for new applications: (1) ICPs powered by continuous radio frequency (0.4–13.56 MHz) in hemispherical, planar, and cylindrical geometries; (2) high-power, pulsed ICPs for plasma-based ion implantation; and (3) inverted ICPs (with a coil inside a dielectric tube) for vacuum chambers with difficult access. We have also studied inductive heating physics with various plasma diagnostics and with theoretical analysis. In particular, the large influence of the induced radio-frequency magnetic fields on low-frequency ICPs has been uncovered for the first time. Finally, we have developed a comprehensive set of plasma and gas diagnostics to gain understanding of how ICPs work and of how to achieve uniform plasmas of the desired composition over increasingly large areas. The above research is performed in part as a collaboration with industries such as Novellus Systems, Inc., Dow Chemical, and North Star Research Corporation.

Alcator C-Mod Tokamak Imaging Diagnostics

G.A.Wurden [(505) 667-5633] (P-24), collaborators from Massachusetts Institute of Technology

A collaboration between Los Alamos and the Massachusetts Institute of Technology (MIT), this project is designed to provide specialized imaging diagnostics to the Alcator C-Mod tokamak. A new digital infrared (IR) camera system and IR periscope, intended to view the heat loads on the inner wall and divertor structures, has been designed, and construction will begin in FY97. Los Alamos delivered a full set of engineering drawings, optical design, and parts lists to MIT. Los Alamos systems at MIT include two fast visible cameras and a neutral-particle, time-of-flight diagnostic.

Columbia HBT-EP Magnetohydrodynamic Feedback Stabilization

G.A.Wurden [(505) 667-5633] (P-24), collaborators from Columbia University

This project is a collaboration between Los Alamos and Columbia University that will provide a high-power, fast-feedback module to the HBT-EP (High-Beta Tokamak—Extended Performance) at Columbia University for the purpose of controlling plasma instabilities in real time. The unit will be used to study the effects of mode locking by using external coils to study driven plasma rotation and disruption prevention. It is the second of a set of two 10-MW, 0- to 30-kHz, 1000-A amplifiers. Although this collaboration was primarily an engineering effort in FY96, in future years we intend to study the underlying physical processes of these instabilities.

Diagnostic Development Relevant to the International Thermonuclear Experimental Reactor

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Los Alamos is participating in a number of diagnostic-development activities that support the International Thermonuclear Experimental Reactor (ITER). We are supporting ongoing US/Japan collaborations with two advanced diagnostic systems under development and testing; this effort was also used to enhance our collaboration with the Tokamak Fusion Test Reactor (TFTR) at Princeton. First, our studies of diamond neutron detectors were concluded at the LAMPF neutron source at Los Alamos. Ongoing efforts with scintillating-fiber, 14-MeV-neutron detectors at the large JT-60U tokamak at the Japanese Atomic Energy Research Institute in Naka, Japan, continued with demonstration of remote diagnostic control over the Internet and of virtual presence at off-site experiments using integrated services digital network (ISDN) video conferencing. We are also designing a new diagnostic that could be applied directly to ITER for eventual prototyping on the new Large Helical Device in Nagoya, Japan. This diagnostic is a state-of-the-art imaging bolometer that will be able to measure the entire spectrum of energies emitted by a hot steady-state plasma. Los Alamos is also conducting scoping studies and doing diagnostic design to support the ITER Engineering Design Activity (EDA). This includes work on some physics R&D issues deemed important by the U.S. home team. In FY96 we worked on Phase I and II designs for several neutron-detector diagnostics (including neutron-activation and source-strength monitors). We also studied the prospects for an intense diagnostic neutral beam to be used for a variety of plasma measurements, especially for active spectroscopy.

Tokamak Fusion Test Reactor Experiment

G.A.Wurden [(505) 667-5633] (P-24), collaborators from Princeton University

This project is an on-going collaboration between Los Alamos and Princeton University on the TFTR experiment at Princeton. Los Alamos fielded a new digital imaging system on an existing periscope to view plasma disruptions, plasma instabilities, and lithium-pellet injection during deuterium-tritium experiments. Los Alamos personnel are studying the sudden and violent demise of the plasma current and the formation of runaway electron tails, circumstances in which several megajoules of energy can be suddenly deposited on the vessel structures. Irradiation studies of Hall-probe magnetic-field sensors also continued in the realistic neutron environment of the TFTR.

A Target Plasma Experiment for Magnetized Target Fusion

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Achieving controlled fusion is a scientific “grand challenge” that has been pursued for over 40 years. Fusion energy would help satisfy the long-term energy needs of the growing population on Earth. Magnetized target fusion (MTF) is an approach to controlled fusion in which a premagnetized, preheated target plasma is near-adiabatically compressed to fusion conditions. The objective of this project is to develop the ability to generate suitable target plasmas for MTF, the first critical milestone in the development path for achieving fusion with the MTF concept. Our approach involves driving a fast-rising electrical current reaching 1–2 MA through a fiber of cryogenically frozen deuterium on the order of 200 mm in diameter. The fiber rapidly turns to plasma, heats, and expands to fill a plasma-containment chamber, thus becoming confined by the walls of the chamber.

This project relies heavily on existing facilities and equipment at the Laboratory that are adapted to our needs. This year, we designed and constructed a power-flow-channel and plasma-chamber system, and we incorporated this system into the Laboratory’s Colt capacitor-bank facility. The capacitor bank has a maximum stored energy of 0.25 MJ, and it delivers a maximum of 3 MA of current with a rise time of 2–3 ms. We have performed initial plasma-formation experiments using a static fill of hydrogen gas. The diagnostics that we have fielded include an array of 12 B-dot probes used to determine plasma current; a 1.3-mm laser interferometer to determine plasma density; an optical framing camera; a gated, optical, multichannel analyzer for visible spectroscopy; a visible/near-ultraviolet monochromator with time resolution for spectral time history; photodiodes to measure light emission; and the usual capacitor-bank monitors. The data show that we are generating a plasma that lasts 10–20 ms with no obvious signs of impurities. Further analysis of the data is ongoing. The results from the 1.3-mm interferometer show that we need to go to a shorter-wavelength laser interferometer to reduce beam deflection caused by density gradients in the plasma and to reduce the overall sensitivity of the system. In accordance, we have borrowed a HeCd laser, purchased the supporting optics, and assembled and bench-tested the new interferometer. We will install the new interferometer on the actual plasma chamber in the near future. We are also refurbishing the cryostat used for making the cryogenically frozen deuterium fibers and will be installing it on the plasma chamber.